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Determining optimum location and capacity for micro hydropower plants in Lorestan province in Iran

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ABSTRACT

In Iran and other developing countries, transmitting electricity power to remote and inaccessible areas is not cost effective and involves a lot of problems due to high transmission costs and insufficient supply. Therefore local water potential would seem a better alternative to supply electricity. This paper is an investigation into all the issues concerning finding suitable sites for micro hydropower plants in remote areas in Lorestan province in Iran. Therefore, the basins, river network, and rural electricity condition in the province were studied. Then, we came up with a list of locations which would lend themselves best to the installation of micro hydropower plants in accordance to the existing parameters. Finally, an estimation of optimum nominal capacity for each micro hydropower was studied and related economic concerns were discussed.

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1. Introduction

The main power network of Lorestan has difficulty supplying electricity to mountainous regions in the province for three main reasons:

- Because of heavy snowfall in the region, the equipment required for the installation of transmission lines need to be extra-strong, thus incurring additional expenses.
- The relevant maintenance costs are particularly high due to the fact that the villages in the areas are far from each other and the roads to them are in extremely poor conditions.
- The third problem is the high rate of energy loss from long transmission lines.

For these reasons it is necessary to find another way of supplying power. Therefore, much attention has been drawn to micro hydropowers thanks to their suitability for remote areas over the past few years. Such power plants are durable, do not pollute the air, do not use fossils fuels, are economical, and are easy to manufacture, setup, and operate. Moreover, if appropriate connection to the main network can be established, energy loss can be reduced, voltage drop can be lowered, and distribution system reliability can be enhanced [1,2].

The Iranian water potential is estimated at 50,000 MWH, of which around 7670 MW is already in operation and about 6600 MW is under construction. Also it is possible to install micro hydropower plants in just over 3000 spots in Iran [3–6]. Additionally, the finding of several preliminary studies by department of energy the Iranian and university researchers suggest that approximately 2700 village in Iran have water potential on appropriately inclined plans within a radius of 10 km in their vicinity [7]. A great majority of these potentials are situated in the northern, western, and central provinces in Iran.

Proper investment in such micro hydropower plants requires a close investigation of existing locations which was carried out a few years ago by an agency under the Iranian department of energy as part of the Iranian water energy plan. Among the micro power plants which came into existence thanks to, as an example the Karnagh hydropower plant with the capacity of 54 kW in the Ardabil province, micro hydropower plant with the capacity of 60 kW in the province of Gilan, micro hydropower plant with the capacity of 25 kW in the province of Northern Khorasan, Maran and Darjan hydropower plant with the capacity of 36 and 52 kW in the province of Mazandaran were inaugurated and being used.

Similar to the Iranian experience, using micro hydropower plants as a source of supplying energy to remote areas is one of the most attractive options in other parts of the world: Malaysia [8], Turkey [9], Greece [10], Algeria [11], Pakistan [12], Finland [13], Rwanda [14], India [15], Bangladesh [16], and Australia [17], to name but a few. Research carried out by Ref. [18] presented an overview of hydropower plants and then examined in detail whether the prevalent belief in the environmentally friendliness of such plants is truly justified. Past research suggests that the widespread use of hydropower plants may save the world from environmental damage. Furthermore [19], using the figure-of-merit method, showed that hydropower is the second best sustainable source for electricity generation behind wind power. Many researchers have attempted to examine different aspects of utilizing this type of renewable energy. Ref. [20] introduced a decision support system (DSS) to analyze the establishment of micro hydro power (MHP) plants from a sustainable development perspective, considering the hydrological, topographical, geotechnical, environmental, energy, economic, and social aspects of the target site. The paper showed that the designed power plants can solve the problem of lack of electrical power in small communities of Brazilian Amazon and can additionally create jobs and generate revenue. As Ref. [21] indicates, with the help of international community, the government of Afghanistan is attempting to develop a new market-oriented approach to the nationwide provision of electrical power, explicitly defining a role for micro hydro generating sources. The paper described a micro hydro project in Padisaw village in the Afghan province of Nuristan, which was undertaken by Provincial Reconstruction Team in cooperation with the local community. In its description of how the Afghan National Development Strategy was executed, the paper offered some observation on how the private sector can play an increasingly significant role in Afghan energy distribution. Ref. [22] analyzed the execution of a set of rural MHP projects in Bolivia, taking a learning-based analytical perspective. Authors in Ref. [23] presented a scheme for private sector participation in micro hydro development project in Rwanda. The paper emphasized the significance of institutional arrangements, local participation, and the collaboration between local private electricity distribution companies and financial firms. Ref. [24] proposed a geographical information system to be used in selecting appropriate sites for small hydropower plants, taking into account engineering, economic, environmental, and social issues.

The present paper is a report on a research project undertaken for Bakhtar Regional Electric Company [7], which aimed at finding suitable location in Lorestan province for micro hydropower plants.

2. Rivers in Lorestan

Since it is adjacent to Zagros mountain range, Lorestan is exposed to two different mass of air, Sudanese hot and humid front and Mediterranean moderate and humid front. Confrontation between these fronts causes much annual rain.

There is an average long-term rainfall of 570 mm in Lorestan making it the country's third rainy region behind Mazandaran Sea and Uremia Lake [25].

The river network in this province is among the richest in Iran which feeds as much as 13.5 billion m^2 into Dez and Jarkhe dams including the water brought in from neighboring provinces.

This volume forms around 11% of all the running waters in Iran whit 4 major rivers and 30 permanent rivers, this network is 2450 km long. In addition geological formations in the province contain as much as 5 m^3 underground water. Tables 1–3 depict the water basins and river network in Lorestan.

3. Lorestan rural power status

The statistic released by Lorestan Power Distribution Company shows that of all the 2590 villages in the province, 43 villages of over 20 households and 227 villages of fewer than 20 households are deprived of electricity. Overall 11% of the villages do not have access to electricity power, which are mainly in mountainous areas

Table 1
Water basins in Lorestan province.

Name	Area (m^2)	Number of separated parts	Number of separated parts in the province or provincial	Area percentage	Surface water (Billion m^3 per year)
Great Karoon	67257	42	5 internal water basins and 2 bordering water basins	57.9	8.05
Karkheh	51643	35	8 internal water basins and 2 bordering water basins	38.1	5.45

Table 2
The distribution of the surface water in the proximity of the DEZ river.

	River	Origin	A (km^2)	Q (m^2/s)	MCM
Dez	Tireh	Golroud	60.4	2.48	78.21
		Sarab Sefid	64.6	1.78	56.13
		Absardeh	223	2.7	85.15
		Biatoon	120	0.52	16.4
		Tireh	960	4.54	143.17
	Marbereh	Azna	2010	4.17	131.15
		Darreh Takht	3665	1.47	46.36
		Kamandan	35	1.45	52.03
	Bakhtiari	–	6390	150.17	4735.75
	Sezar	–	9200	104.15	3284.47

and devoid of suitable access road and infrastructure required for the installation of power network.

The rural power status of the province is displayed in Table 4. Based on the condition and potential of the region, the electricity required can be supplemented in any of the following ways:

- Biogas.
- Solar generator.
- Wind power.
- Diesel generator.
- Micro hydropower plant

The above-mentioned facts about Lorestan province would make micro hydropower plants the best alternative to supply electrical energy to remote areas. Incidental to this will be the advent of small industries, more job opportunities, socio-economic development and less migration to urban areas. Not only that, having access to electricity, people in these areas would no longer fell trees for fuel, which would have otherwise disturbed the ecological balance in the region.

4. Determining the potential of micro power plants in Lorestan

From the point of view of production capacity, hydro power plants are generally divided up into the following categories [6]:

- Large hydropower plants: a nominal capacity of over 50 MW of the electricity.
- Small hydropower plants: able to produce between 500 kW to 50 MW of electricity.
- Mini hydropower plants: able to nominally produce between 200 kW and 500 kW of electricity.
- Micro hydropower plants: a nominal capacity of less than 200 kW of electricity.

In this study, finding the best location for micro hydropower plants was sought according to the following criteria:

- Adequacy of hydro potential.
- Proximity to the distribution network and potential subscribers.
- Suitability of location for the installation of associated structures.
- Minimal adverse effect on local agriculture.
- Easy accessibility of the site.
- Sufficiency of the water flow at different times of the year.
- Availability and transportability of construction materials.

The suitable spots were determined in the following process.

4.1. Determining the spots on topographical maps

First all the rivers were spotted on the topographical maps of the province. Then given the degree of the slope of the river and

Table 3
The distribution of the surface water in the proximity of the Karkheh river.

	River	Origin	A (km^2)	Q (m^2/s)	MCM
Karkheh	Simareh	Badavar	615	3.18	100.13
		Darreh Dozdan	568	1.47	68.2
	Kashkan	Herood Dehnoo	270	2.77	87.2
		Herood Kaka Reza	1148	10.62	334.75
		Darreh Tang Aleshtar	166	3.01	94.92
		Sarab Seydali Aleshtar	773	6.87	216.49
		Cham Anjir	1590	10.76	339.33
		Doab Veysan	2450	9.33	294.23
		Kaka Sharaf	234	1.72	54.08
		Pol Kashkan	3670	26.63	839.65
		Afrineh	6700	40.27	1269.8
		Cholhool	800	3.51	110.53
		Madian Rood	1108	1.66	52.19
		Poldokhtar	9140	46	1450.5

Table 4
Status of utility in rural region of Lorestan province.

City	Villages with electricity					Villages without electricity but capable of having electricity			Villages without electricity and incapable of having electricity			Villages without electricity and about to have electricity (in the year 2010)		
	Over 20 Households	Over 15 Households	Over 10 Households	Under 10 Households	Sum total	Over 20 Households	Under 20 Households	Sum total	Over 20 Households	Under 20 Households	Sum total	Over 20 Households	Under 20 Households	Sum total
Khoramabad	403	92	114	72	681	1	18	19	4	29	33	1	3	4
Borujerd	125	13	11	6	155	0	8	8	0	0	0	0	0	0
Aligodarz	151	27	35	21	234	0	3	3	27	12	39	1	0	1
Koohdasht	183	45	31	13	272	0	12	12	0	3	3	0	1	1
Dorood	99	11	14	8	132	0	1	1	0	1	1	0	0	0
Azna	78	2	2	7	89	0	1	1	0	0	0	0	0	0
NoorAbad	218	58	57	14	347	1	22	23	2	42	44	0	0	0
Aleshtar	129	34	41	17	221	0	3	3	0	4	4	0	0	0
Poldokhtar	113	45	34	22	214	0	18	18	4	34	38	0	0	0
Sum Total	1499	327	339	180	2345	2	86	88	37	125	162	2	4	6

associated mountains, all the spots which seemed amenable to constructing canals and dams were determined. Finally, of these spots, those with a proper height difference (Head) between the construction site of the dam and that of the power plant were noted as suitable location for micro hydropower plants.

4.2. Validating the spots with local expert experience

At this stage, the chosen spots were verified with expert personnel working for the regional water and electricity companies in terms of accessibility, proximity to the main network and subscribers, and height. Other considerations which were checked were flow rate of the rivers and when they have their largest volume.

4.3. Visiting the spots for identified on map

In order to check suitable spots and to subsequently estimate the obtainable power, a form was created so that all the consideration regarding each spot and the potential associated power plant could be captured. To complete the forms, a group of geologists, hydrologists, and electricians together with an experienced local visited the spots identified on topographical maps. Below comes a brief description for some of the more important considerations by the group while determining the power plant site:

4.3.1. Determining of the flow rate

The flow rate of a river can either be directly measured using the stations installed or roughly estimated through measuring the area of the water basin and the seasonal precipitation of the region.

4.3.2. Determining the head

The head is the height difference between where a dam is constructed and where a power plant is installed. This difference is obtained using a GPS device at preliminary stages and detailed topographical maps at later stages.

4.3.3. Determining the type of power plant

Micro hydropower plants can generate electricity from running or confined water. The former requires no dam to be built on the stream of water. Indeed, if any dam at all is constructed with this kind of power plants, it is to divert the course of water to the main water canal. The problem with this type is that the amount of electricity it generates varies with the seasonal fluctuations in the flow rate of the river. These fluctuations can be compensated by collecting superfluous water in a reservoir with a gate which can be opened in times of need.

Determining the type of power plants demands the year-round volume of the river be known. To find this, the bed of the river is flattened so that a scale can be installed for the purpose of measuring water level on a regular basis. As a result, a curve is drawn that gives monthly, seasonal, and yearly representations of the maximum, average, and minimum flow rates of the river.

4.3.4. Determining the best location for the dam

A diversionary dam constitutes an important and expensive part of a micro hydropower plant. The spot where such a dam is constructed should be easily accessible, geologically appropriate, and close to the side of a river. Another important consideration is that the course of the river should be devoid of any major turn and twist.

4.3.5. Determining the course of a canal

The course of a canal is determined with technical and economic issue in mind. High-pressure pips at the end of the canal convey water to the turbines.

Table 5
Where those 10 power plants should be installed.

Row	Location	City	Flow rate (L/s)	height of dam (m)	Height of power plant (m)
1	Fesharshekan 1	Borujerd	200	2014	1981
2	Fesharshekan 2	Borujerd	200	1981	1904
3	Fesharshekan 3	Borujerd	200	1904	1808
4	Venayi 1	Borujerd	350	1981	1891
5	Venayi 2	Borujerd	250	1891	1865
6	Keygoran	Khoramabad	120	2174	2014
7	Derakhtchaman 1	Khoramabad	120	1729	1721
8	Derakhtchaman 2	Khoramabad	120	1721	1687
9	Haft Cheshmeh 1	Khoramabad	80	1715	1669
10	Haft Cheshmeh 2	Khoramabad	80	1669	1598

4.3.6. Chain power plant

It may possible to build serial power plant where the water flows from one power plant to another via canals. In this system, it is only for the first power plant that a diversionary dam is constructed. The electricity generated by all the power plants in the series can be consolidated in parallel. Therefore, such power plants reduce energy production costs and increase economic efficiency.

4.3.7. Power plant operation status

A micro hydropower plant can operate either stand-alone or grid-connected. The former mode is more appropriate for remote areas, where there is little demand for electricity. On the other hand, in the event that a micro hydropower plant produces electricity in excess of the local demand, it can be connected to the main network on the condition of proximity. This can thus reduce energy loss and assist the network in low-production seasons. The detail of this connection is beyond the scope of this paper.

4.3.8. Multi-purpose power plants

To be more efficient, a micro hydropower plant can also provide the water needed for drinking, irrigation, and fishpond.

5. Results

In line with the objectives of the study, the following results were obtained.

5.1. Micro hydro potential of Lorestan province

A total of 75 spots were identified across the province, which would lend themselves to installing micro hydropower plants. Then relevant data were gathered and accurate measurement was carried out in order design suitable power plant and to estimate their energy generation capacity.

5.2. Top-priority micro hydro potentials

Given parameters such as proximity to customers, unnecessariness of a long power distribution network, presence of village without electricity, and availability of suitable access road, 36 of the 75 spots identified in preliminary studies were shortlisted.

5.3. Detailed specification of shortlisted spots

Of the hand-picked spots, 17 were visited for further investigation. More specifically, the flow rate and height of the rivers involved were measured. Flow rate measurement was intentionally performed in a low-precipitation season so that we could make sure the estimated capacity would always be realizable.

5.4. Detailed specification of mapped locations

The 17 spots were further reduced to 10 according to the criteria below:

- The urgency of the need for electricity.
- Optimality of the height and flow rate of the river involved.
- The possibility of using the prospective power plan for agricultural and irrigation purpose.
- Local availability of the materials required to construct the power plant and of the workforce required to develop and maintain the installations and transmission lines.

Table 5 specifies where those 10 power plants should be installed.

6. Designing case study

6.1. Selected sites

Finally, 5 locations were selected for detailed design and installation by available investors. The calculation was done according to standards and the results are shown in Table 6.

It should be mentioned that the energy generated is a function of the head and flow rate and can be calculated as below [26]:

$$P = \frac{\gamma Q H \eta}{1000}$$

where, p: turbine output (in kW); H: height (head) (in m); Q: turbine flow rate (in m^3/s); γ: specific gravity (in N/m^3); η: turbine efficiency.

The values for turbine efficiency are first selected tentatively and are finally set according to laboratory values. The initial values in the formula above are 93% for Francis and Propeller turbines and 90% for Pelton and Tubular turbines [26,27].

Thorough calculations were carried out for Keygoran and Fesharshekan 2 upon existing standards and software applications. These calculations entailed making a number of choices as follow:

- The type of dam.
- The method of caring water to the turbine.
- The type and size of turbine based on the head and flow rate.
- The type and size of the generator.
- Electrical and control equipment including substation, switchgear, governor, and transmission.

6.2. Economic considerations

Keygoran and Fesharshekan 2 sites were studied in terms of economic considerations which included all the cost and expenses associated with power plant construction, installation, and equipment. It was turned out that the cost of electricity generation is 670

Table 6
Calculation of turbine.

Row	Name	City	Flow rate (L/s)	Head (m)	Power (kW)	Power (kVA)	Turbine type	Specific speed (m kW)	Speed (rpm)	Jet diameter (m)	Actual nq (m kW)
1	Fesharshekan 3	Borujerd	200	90	160	200	Pelton	44	600	0.0817	9.18
2	Venayi 1	Borujerd	250	85	180	225	Pelton	31.18	600	0.086	15.15
3	Keygoran	Khoramabad	120	155	135	169	Pelton	35.55	1500	0.054	10.52
4	Fesharshekan 2	Borujerd	200	77	132	165	Pelton	31.23	600	0.082	11.82
5	Haft Cheshmeh 2	Khoramabad	80	71	50	60	Cross flow	51.46	1500	0.054	17.3

USD per kilowatt. Now given that the guaranteed price of energy is 77 cents for each kwh of electricity in Iran, the money spent will return in less than a year (around 330 days, to be exact) provided that the power plant is in operation at rated capacity round the clock.

It is worth noting that the micro hydro turbine-generators have a lifetime of about 50 years and will not require overhaul until 2.5 years after installation as claimed by the manufacturers.

7. Conclusion

Given the difficulty of supplying remote areas with the electricity from the main power network, using local water potentials offers a good alternative economically and socially. This paper was aimed at determining optimum locations in Lorestan province for micro hydropower plants. Accordingly, 75 sites were subsequently reduced to 10 based on thorough calculations. In addition, two of these locations were subjected to further economic and technical calculation. The results are an indicator that the micro hydropower plant is a cost-effectiveness way of supplying electricity to rural networks.

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